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SIMULATION AND ANALYSIS OF WIND TURBINE WAKES

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Abstract. Modern wind turbines are often clustered in wind farms in which the turbines are fully or partially influenced by the wake of upstream located turbines. As a consequence, the wake behind the wind turbines has a lower mean wind speed and an increased turbulence level, as compared to the undisturbed flow outside the farm. Hence, wake interaction leads to a decreased total production of power, caused by lower kinetic energy in the wind, and an increase in the turbulence intensity. The turbulence created from wind turbine wakes is mainly due to the presence of the distinct tip and root vortices, which eventually break down and forms small-scale turbulent structures. If a wind turbine is located in a wake consisting of tip and root vortices, the fatigue loading is more severe than in the case where the tip vortices have already broken down by instability mechanisms. Therefore, understanding the physical nature of the vortices and their dynamics in the wake of a turbine is important for the optimal design of a wind farm.

In the past years, wakes behind wind turbine blades have been studied both experimentally and numerically, using analytical tools as well as numerical simulations based on RANS or LES methodologies combined with actuator disc or line techniques ([1]). From these studies it has been shown that helical wakes are inherent unstable and that the flow inside a wind farm to a large extent is depending on the ambient turbulence and the stability properties of the atmospheric boundary ([2], [3]).

In the present work we study the near wake behavior of a wind turbine in order to elucidate the impact of the tip- and root vortices on the turbulence characteristics and in particular on the length of the near wake. The numerical model is based on large-eddy simulations (LES) of the Navier-Stokes equations using the actuator line (ACL) method. The wake is perturbed by applying stochastic or harmonic excitations in the neighborhood of the tips of the blades. The flow field is then analyzed to obtain the stability properties of the tip vortices in the wake of the wind turbine. As a main outcome of the study it is found that the amplification of specific waves (traveling structures) along the tip vortex spirals is responsible for triggering the instability leading to wake breakdown. The analysis furthermore leads to a simple expression for determining the length of the near wake. This expression shows that the near wake length is inversely proportional to thrust and tip speed ratio and direct proportional to the logarithmic of the turbulence intensity.

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